

10.10 DEVELOPMENT OF QUALITY ASSURANCE AND QUALITY CONTROL GUIDANCE FOR GROUND-BASED REMOTE SENSORS FOR USE IN REGULATORY MONITORING

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1. INTRODUCTION

Sodars, wind profiling radars, and radio acoustic sounding systems (RASS) have played an important role in atmospheric boundary layer studies over the last two decades. These ground-based remote sensors have gained a reputation as effective and reliable tools for acquiring detailed information on atmospheric wind and temperature structure. Numerous studies have also shown that estimates of mixed layer height, atmospheric stability, and turbulent fluxes of heat and momentum can be obtained by these systems. The capabilities of these sensors and how they are used to investigate various boundary layer problems are extensively discussed by Clifford et al. (1994). However, their acceptance by the regulatory community in the past has lagged.

The use of these remote sensors has been approved on a case-by-case basis by the Environmental Protection Agency (EPA) to develop meteorological databases for transport and dispersion models. One of the reasons for the under utilization of this technology is that many EPA dispersion models require only the very simplest meteorological data for input. In some instances, only surface data would be required to model the boundary layer processes responsible for the fate of air pollution constituents. But as EPA models become more sophisticated, so must their input data. For example, the Photochemical Assessment Monitoring Station (PAMS) network requires extensive data collection in ozone nonattainment areas which are classified as serious, severe or extreme. The agencies responsible for acquiring these data in urban regions must include atmospheric boundary layer profiles of wind and temperature. These data can be used as input into the Urban Airshed Model (EPA, 1990) for assessment of ozone production, transport, and removal. The use of sodars, radars, and RASS are being considered by EPA as viable tools for PAMS (Crescenti, 1994) as well as other regulatory

programs. One such station is located at Rutgers University in New Brunswick, New Jersey (Frederick et al., 1994). This PAMS includes an instrumented 20-m tower, sodar, wind profiling radar, and RASS.

The regional, state, or local agency which must implement a PAMS-type program requires detailed quality assurance (QA) and quality control (QC) guidance on ground-based remote sensors. However, there is a distinct void in the current EPA guidance which does not adequately address the use of remote sensors for regulatory applications. The *On-Site Meteorological Program Guidance for Regulatory Modeling Applications* (EPA, 1987) includes a chapter on sodar QA/QC which is a decade old and has become somewhat outdated. Radars and RASS are not discussed in this document. Within the last year, the *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements* (EPA, 1989) has been revised to include a new section on QA/QC for all three types of ground-based remote sensors. While this section provides an overview on QA/QC guidance on these remote sensors, it is still limited in the amount of detail or information needed by potential users.

EPA is in the process of developing comprehensive QA/QC guidance on the use of sodars, radars, and RASS for regulatory applications. This document will be based on methods and data obtained from past research studies. It will also be based on results from a recent experiment which is described in Section 2. Section 3 briefly discusses the issues of siting, installation, acceptance testing, calibration, performance audits, routine operation and maintenance, tear down, data processing techniques, and expected performance statistics as a function of atmospheric conditions and sensor configuration. A summary is given in Section 4.

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2. DESCRIPTION OF EXPERIMENT

The Ground-Based Remote Sensor Characterization Study was conducted in April 1995 at the Boulder Atmospheric Observatory (BAO) in Erie, Colorado. A detailed description of the facility and its 300-m tower is given by Kaimal and Gaynor (1983). The objective of the study was to obtain information on QA/QC methods and procedures which would lead to the acquisition of wind and temperature profiles of known quality. In addition, data from these ground-based sensors were acquired so that an assessment can be made about their performance for various atmospheric conditions and sensor configuration. An extensive meteorological data set was acquired from a suite of *in situ* instrumentation mounted on the BAO tower. The ground-based remote sensors included four commercial sodars, a 915 MHz radar wind profiler and RASS, a 449 MHz RASS, and a FM-CW radar. The locations of these instruments are shown in Figure 1.

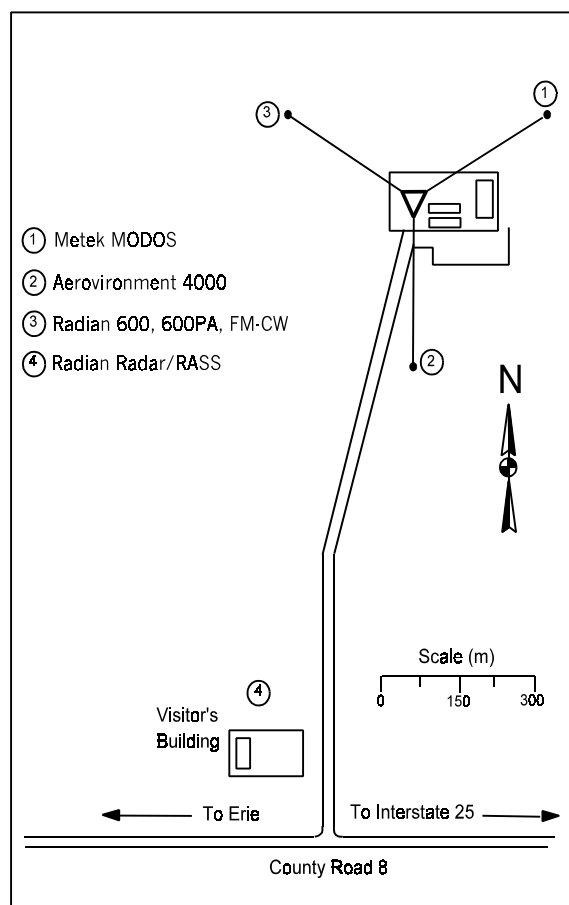


Figure 1. Locations of remote sensors.

2.1 Tower Instrumentation

The 300-m BAO tower was instrumented with a suite of *in situ* sensors. R. M. Young wind monitors were used to measure horizontal wind speed and direction at 10, 50, 100, 200, and 300 m. Ambient air temperature and relative humidity were measured at the same levels using Vaisala HMP-35A probes. These sensors were housed inside R. M. Young Gill aspirated radiation shields to minimize measurement errors associated with solar heating. Platinum temperature probes housed in Gill aspirated radiation shields were located at 10 and 50 m for temperature gradient measurements. Campbell Scientific CR10 data loggers were placed at each instrument level to record these data as 15-minute averages. The five data loggers were networked into a computer located inside a trailer adjacent to the tower.

Turbulent flux measurements were obtained using five Applied Technologies sonic anemometers. These sensors were also mounted at 10, 50, 100, 200, and 300 m. The three component wind velocity and virtual air temperature were sampled at 10 Hz by a 486 PC and recorded in their raw form to an optical disk. The 15-minute means, standard deviations, and covariances of these four variables were also recorded.

Other surface measurements included global solar radiation, barometric pressure and precipitation. These data were also recorded as 15-minute means.

2.2 Sodars

Four sodars were placed around the perimeter of the BAO tower. An Aerovironment model 4000 phased array mini-sodar was located near the south guy wire anchor point. A Metek model MODOS 3-axis sodar was located at the northeast guy wire anchor point. A Radian model 600 3-axis sodar and Radian model 600PA phased array sodar were located at the northwest guy wire anchor point. This distance of the outside guy wire anchor points to the base of the tower is approximately 275 m. The off-vertical beams from the sodars were oriented away from the tower so that reflections from the tower and its guy wires were avoided. In addition, this strategy minimized the chance that acoustic echoes from one sodar system would not contaminated the data of another system. All four sodars recorded profiles of horizontal and vertical wind velocity as 15-minute averages. Each sodar also recorded other parameters such as the signal-to-noise ratio, the number of return signals used in the average, and the amplitude of the returned signal. Some basic sodar specifications are listed in Table 1.

Table 1
Sodar specifications used in characterization study.

	Aerovironment 4000	Metek MODOS	Radian 600	Radian 600PA
Type	phased array	3-axis	3-axis	phased array
Frequency (KHz)	4500	2009	1850	2125
Pulse Width (ms)	50	150	150	150
Pulse Interval (s)	1	4	4	4
Zenith Angle (deg)	18	20	18	14.87
U-Axis Beam Direction (deg)	173	101	302	349
V-Axis Beam Direction (deg)	83	11	215	259
Minimum Height (m)	10	50	50	50
Maximum Height (m)	200	650	700	700
Gate Width (m)	5	25	25	25

2.3 915 MHz Radar Wind Profiler and RASS

A Radian 915 MHz radar wind profiler was used to acquire profiles of horizontal and vertical wind velocity. RASS was used in conjunction with the wind profiler to obtain profiles of virtual air temperature. Two 25-minute wind profiles were acquired each hour by the wind profiler while two 5-minute temperature profiles were acquired each hour by the RASS.

2.4 449 MHz RASS

A NOAA 449 MHz RASS system was also included in the study. This system was located about 12 km northwest of the tower near the town of Erie. The RASS acquired profiles of virtual air temperature and vertical wind velocity.

2.5 FM-CW Radar

A Radian 2.1 GHz FM-CW radar, on loan from the White Sands Missile Range, was included in the study to obtain fine scale structure of the atmospheric boundary layer. While there are no plans to develop guidance for such an instrument, the data from this radar will be of great value in establishing the turbulent character of the boundary layer and in turn, its effects on sodar, wind profiling radar, and RASS performance.

3. QA/QC GUIDANCE DEVELOPMENT

A detailed guidance document on ground-based remote sensors is needed for regulatory monitoring. This document will be written generically to encompass common procedures which can be applied to any type of remote system. The key issues include siting, installation, acceptance testing, calibration, performance audits, routine operation and maintenance, tear down, data processing techniques, and expected performance statistics as a function of atmospheric conditions and sensor configuration. Each issue is briefly discussed below.

3.1 Siting

Not all regulatory monitoring sites will be ideally suited for ground-based remote sensors. There are numerous logistical problems which must be dealt with. However, the two biggest obstacles are ground-clutter and noise interference. Wind profiling radars are susceptible to reflections from plants, trees, and metal objects (Gaynor, 1994). This problem becomes magnified when these objects are subject to movement (e.g., swaying trees or powerlines), thereby creating Doppler shifts which contaminate the lowest several gates of data. Data from sodars are susceptible to noise interference. This noise can manifest itself as fixed echoes off of solid objects. Ambient background noise from traffic, machinery, or

other sources can degrade a sodar's ability to receive return echoes. Acoustic output signals from both sodars and RASS can also be an annoyance to those living in nearby residential areas.

3.2 Installation

Installation issues include securing a shelter (with heating and air conditioning) for housing the remote sensor electronics, access to a well regulated and grounded 110 VAC electric power line, proper procedures for orienting, leveling and guying antenna arrays, and securing the site to avoid inadvertent damage due to human or wildlife activity.

3.3 Acceptance Testing

Once a remote sensor has been properly installed, turning the system on and walking away does not necessarily insure that reliable data will be collected. There are numerous "tweaking" procedures that must take place to optimize a system for a given location. Some sort of comparison, at least in a broad sense, is needed to assure the user that the data being returned by the remote sensor is realistic. This can be accomplished with the use of nearby towers, another remote sensor, or using balloon-based systems such as tethersondes or rawinsondes. Given significant resources, comparisons for acceptance can be achieved by using aircraft. However, given a very restricted budget with no access to the above mentioned measurement systems, then other procedures must be developed for acceptance. This may come in the form of comparing profile data against a series of synoptic weather maps generated by the National Weather Service. Guidance needs to be developed on optimizing the remote sensor in the event of nonacceptance.

3.4 Calibration

A ground-based remote sensor can not, of course, be calibrated inside a wind tunnel. However, steps can be taken to verify individual electronic components of a remote sensor. For instance, the output frequency from an acoustic transducer can be verified with a transponder system (Baxter, 1994a). The remote system is assumed to be calibrated if the sum of its major components operate within specified tolerances.

3.5 Audit

An independent audit is an essential part the QA/QC process which ensures that reliable data are being acquired (Templeman, 1994). Performance audit procedures (Baxter, 1994b) may include, but are not limited to, evaluation of site characteristics, equipment

alignment, simulating wind velocities with an acoustic pulse transponder, independent wind measurement comparisons (e.g., tethersonde), and electronic consistency checks.

3.6 Operation and Maintenance

Remote sensors require some minimum level of oversight by an operator who may or may not be on-site. There may be some instances where components of the system will fail. When this eventuality occurs, steps must be taken to remedy the situation. General maintenance will also be needed to ensure that the remote sensor is not compromised by either human or wildlife intervention or by severe weather events. This may be accomplished by inspecting the system on a routine basis. A level of QC is needed on these data; this can be accomplished by automatic algorithms and/or by operator inspection on a routine basis.

3.7 Tear Down

An assessment should be made on the condition of any remote sensor when it is dismantled at the end of a monitoring study. This is especially critical for long-term deployments. All components should be examined for significant degradation. Examples may include disintegration of acoustic foam linings of sodar clutter fences, cable cracks, and loose electronic connections. Deterioration of critical remote sensor components may lead to less reliable and/or a loss of data.

3.8 Data Processing Techniques

Data processing techniques employed by each vendor are not necessarily the same. While the algorithms are proprietary, the user should understand the fundamental techniques used by a remote sensor to produce its data. For example, the vertical wind velocity may or may not be forced to a value of zero over long-term averaging. This forcing to zero has implications on the magnitude of the horizontal wind velocity which is corrected by coordinate rotation. This is an important consideration when monitoring in complex terrain where the wind velocity as a significant vertical component. Signal-to-noise rejection techniques may also vary. Again, this has important implications on the quality and reliability of the output data.

3.9 Performance Statistics

The database generated from the BAO study will help establish some basic performance statistics. This will be done as a collective for each type of remote sensor. Statistical parameters such as the bias, comparability, and

precision will be computed as a function of time of day, height, atmospheric stability, mean wind velocity, signal-to-noise ratio, and for the number of returned signals used in a given averaging period. This will help establish a confidence level for these data under various atmospheric conditions.

4. SUMMARY

This paper briefly summarizes EPA efforts to develop comprehensive quality assurance and quality control guidance for sodars, wind profiling radars and radio acoustic sounding systems which may be used in a variety of regulatory monitoring programs. Data from past studies and from the 1995 Ground-Based Remote sensor characterization study will be helpful in creating a detailed guidance document for all potential users. Some key issues have been briefly discussed on procedures to ensure high quality data acquisition. Because of the limited space in this forum, many of the details have been omitted. However, each of these key issues will be expanded on and fully discussed in the future QA/QC document.

5. ACKNOWLEDGEMENTS

The author wishes express sincere thanks to Brian Templeman and Catherine Russell for their extraordinary effort in making the 1995 Ground-Based Remote Sensor Characterization Study a success. Thanks are also extended to the commercial vendors for their cooperation and sharing their insights on the challenges of collecting upper-air data. Special thanks to John Gaynor, Richard Scheffe and William Mitchell for their helpful review and comments on this paper.

6. DISCLAIMER

This document has been reviewed in accordance with U. S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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